



(19) Europäisches Patentamt
European Patent Office
Office européen des brevets.



(11) Publication number : 0 657 658 A1

(12)

EUROPEAN PATENT APPLICATION

(21) Application number : 94630066.2

(51) Int. Cl.⁶ : F16C 33/64, F16C 33/14,
C23C 22/73, C23F 3/00

(22) Date of filing : 08.12.94

(30) Priority : 09.12.93 US 164477

(72) Inventor : Hashimoto, Fukuo F.H.
1325 Westview Cir., S.E.
North Canton, Ohio 44720 (US)
Inventor : Howlett, Kevin
1939 Diamond St. N.E.
North Canton, Ohio 44721 (US)
Inventor : Zhou, Rao-Sheng
9686 Beryl St. N.W.
Canal Fulton, Ohio 44614 (US)

(43) Date of publication of application :
14.06.95 Bulletin 95/24

(74) Representative : Schmitz, Jean-Marie et al
Dennemeyer & Associates Sarl
P.O. Box 1502
L-1015 Luxembourg (LU)

(84) Designated Contracting States :
DE FR GB SE

(71) Applicant : THE TIMKEN COMPANY
1835 Dueber Avenue, S.W.
Canton, Ohio 44706-2798 (US)

(54) Process for finishing bearing surfaces.

(57) A roller bearing has working surfaces, that is surfaces where its rollers and races contact each other, which have extremely shallow irregularities that are nondirectional and thus render the working surfaces isotropic. Moreover, the isotropic surfaces have very low average asperity slopes and likewise a very low plasticity indexes. To derive the high quality working surfaces, the races and rollers are first ground or otherwise mechanically machined to provide the working surfaces with the proper profiles. Then the races and rollers are immersed in a liquid chemical which reacts with the metal at the surfaces and contemporaneously forms a protective coating which inhibits further reaction. Abrading elements within the chemical come against the races and rollers as they are agitated and continuously remove the coating from higher elevations of the working surfaces, so that the chemical continues to react with the metal at those higher elevations. The irregularities diminish to very shallow pits of no particular orientation, thus leaving the working surfaces isotropic. Thereafter, in the absence of the chemical, the protective coating is removed, exposing the high quality working surface. The bearing requires no run in, that is to say, after the initial loading its torque and temperature remain steady at low magnitudes. Moreover, the isotropic surface imparts greater fatigue life.

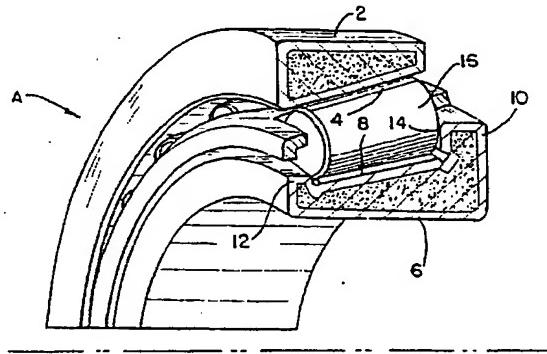
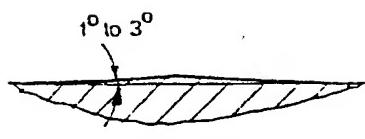


FIG. 1A.

EP 0 657 658 A1

Jouve, 18, rue Saint-Denis, 75001 PARIS



Isotropic Finish

FIG. 2E.

Background of the Invention

This invention relates in general to antifriction bearings and, more particularly, to such bearings having superior finishes on their critical working surfaces and a process for providing such bearings.

From the standpoint of antifriction bearings, the tapered roller bearing has a rather complex geometry. A single row tapered roller bearing, which is the most fundamental of that type of bearing, has two races, called the cup and the cone, each provided with a tapered raceway, and tapered rollers arranged in a single row between the raceways of the cup and the cone. Generally speaking, line contact exists between the tapered side faces of the rollers and the raceways. In addition, one of the races, usually the cone, has a thrust rib against which the large ends of the rollers bear. Indeed, were it not for the thrust rib, the rollers would be expelled from the annular space between the raceways, since radial loads transmitted through the rollers translate into small axial components which urge the rollers up the tapers of the raceways - and against the thrust rib.

Initial impressions would suggest that the two raceways and the side faces of the rollers should lie in conical envelopes having their apexes at a common point along the axis of rotation, for this would produce pure rolling contact between the side faces of the rollers and the raceways. In actual practice, the roller side faces and the raceways have slightly curved profiles to alleviate edge loading and accommodate eccentricity imparted by the load. Considerable research has focused on deriving the ideal configurations for raceways and roller side faces, and algorithms exist for determining those configurations. See U.S. Patent 4,877,340.

Apart from that, one would, upon initial consideration, conclude that the large end faces of the rollers should be squared off with respect to the axes of the rollers. Actually the end faces have a slightly spherical profile, for this enables the rollers, upon bearing against the thrust rib, to acquire the proper orientation along the raceways.

The typical bearing is finished to within close tolerances with a final grind on its critical working surfaces. But in some bearings, the finishing along the working surface is carried farther to reduce the run-in period for the bearing and to enable it to operate at lower torques and with less heat generation. These bearings have enhanced finishes. A bearing with an enhanced finish receives rough grind on its critical surfaces, then a finish grind, and finally honing or superfinishing. An enhanced finish possesses some roughness - as do all surfaces - but the roughness is of a microscopic character. Generally, it ranges between 3 and 8 μin Ra (Ra stands for arithmetic mean roughness - μin for microinch or one-millionth of an inch), which is superior to a minimum of 6 to 10 μin Ra, and more often 15 to 25 μin Ra, one finds on the working surfaces of bearings which are finished with nothing more than a final grind. Grinding and honing, however, produce directional surface textures, with the surface irregularities, minute as they may be, extending in the circumferential direction. Indeed, current machining practices leave the circumferential orientation as the only orientation available. But the circumferential orientation does the least to facilitate lubrication along the line of contact between the raceways and the side faces of the rollers.

In this regard, N. Patir and H. S. Cheng, in their paper entitled An Average Flow Model for Determining Effects of Three-Dimensional Roughness on Partial Hydrodynamic Lubrication, Transactions of the ASME, Vol. 100, page 12, January 1978, examined orientations of microscopic surface irregularities in connection with their effects on lubrication and concluded that a surface composed of irregularities extended longitudinally in the direction of movement renders the lubricant less effective than a surface having irregularities extended transversely to the direction of movement, and that an isotropic surface, that is one which has no orientation to its irregularities, is superior to a surface composed of longitudinal orientations. Translated to bearings, the typical machining process leaves the raceways and roller side faces with machining marks in the form of circumferentially directed grooves which tend to diminish the thickness of the hydrodynamic oil film which exists between the raceways and rollers, and this holds true even with respect to bearings having enhanced finishes.

So-called barrel finishing, that is to say, tumbling a part within a corrosive environment, will leave a surface with minute irregularities that are quite shallow, but the traditional barrel finishing procedures destroy the precision profiles to which the roller side faces and raceways are machined. Thus, traditional barrel finishing does not represent an acceptable substitute for producing a bearing with an improved finish.

The present invention resides in a process for providing superior working surfaces for bearing components. Usually the races and rollers on which those working surfaces exist are machined, ultimately by grinding, such that those surfaces have the desired profiles. Then some or all of these components are subjected to a further finishing which leaves the surface with irregularities on the order of 1 to 3 μin Ra. The irregularities have no orientation and thus render the surface isotropic. The invention also resides in an antifriction bearing having working surfaces with isotropic finishes.

Description of the Drawings

In the accompanying drawings which form part of the specification and wherein like numerals and letters refer to like parts wherever they occur.

- 5 Fig. 1 is a perspective view, partially cut away and in section, of a tapered roller bearing finished with isotropic working surfaces in accordance with the present invention, and further showing an individual roller separate and in elevation;
- 10 Fig. 2 depicts tracings derived from two surfaces, one having a traditional enhanced finish and the other an isotropic finish of the present invention, and further provides characteristics of such surfaces;
- 15 Fig. 3 shows in perspective a surface with traditional enhanced finish and a surface with an isotropic finish; Fig. 4 are highly magnified photographic representations of a surface with traditional enhanced finish and a surface with an isotropic finish of the present invention;
- Fig. 5 is a graph comparing the operating temperatures of two bearings, one having a traditional enhanced finish and the other an isotropic finish, during the initial hours of operation; and
- Fig. 6 is a graph comparing the operating torque of two bearings, one having a traditional enhanced finish and the other an isotropic finish, during the initial hours of operation.

Detailed Description

20 Referring to the drawings, a bearing A (Fig. 1) operates at low internal torque and generates relatively little heat from the very outset. Indeed, it requires no so-called "run-in" to condition its working surfaces, which are, of course, the surfaces against which the major components of the bearings contact each other. As such, the temperature and torque of the bearing A remain constant from the very outset of operation, save for the short time required for the bearing A to reach its normal operating temperature. To this end, at least one of the working 25 surfaces of the bearing A has very shallow surface irregularities of a microscopic character, and these irregularities are without orientation, that is to say, the surface is isotropic. Preferably, all of the working surfaces have these characteristics. The surfaces derive from traditional grinding followed by a vibratory-chemical finishing operation that is basically set forth in U.S. Patent 4,491,500.

30 The process is particularly useful for finishing the working surfaces of tapered roller bearings, and the bearing A is such a bearing in its most basic configuration, that is with its rolling elements organized in a single circular row around the axis X of rotation. The bearing A includes (Fig. 1) an outer race or cup 2 having a tapered raceway 4 which is presented inwardly toward the axis X of rotation. The raceway 4 represents the working surface of the cup 2. In addition, the bearing A has an inner race or cone 6 provided with a tapered raceway 8 which is presented outwardly away from the axis X of rotation, and inasmuch as the cone 6 lies within the 35 cup 2, the cone raceway 8 is presented toward the cup raceway 4. The cone raceway 8 lies between large and small ribs 10 and 12 which project outwardly beyond the raceway 8. The large rib 10, also known as a thrust rib, has a rib face 14 located at the large end of the tapered raceway 8. The raceway 8 and rib face 14 constitute the working surfaces of the cone 6. Finally, the bearing A has tapered rollers 16 arranged in a single circumferential row between the cup 2 and cone 6, that is to say, in the annular space formed by the spaced 40 apart, yet opposed, raceways 4 and 8. Each roller 16 has a tapered side face 18 which contacts the two raceways 4 and 8, there being, generally speaking, line contact between the roller side faces 18 and the raceways 4 and 8. Each roller 8 also has an end face 20 which extends out to the large end of the side face 18 and a recess 22 opening out of the end face 20, thus giving the end face 18 an annular configuration. The end face 20 has a slightly spherical profile, that is to say, it lies within an envelope having the shape of a sphere. The 45 distance between the two ribs 10 and 12 slightly exceeds the length of rollers 16, and indeed it must to enable the rollers 16 to properly seat along the raceways 4 and 8 and against the rib face 14. The side faces 18 and end faces 20 form the working surfaces of the rollers 16. While the traditional tapered roller bearing has its thrust rib 10 at the large end of the cone raceway 8, some tapered roller bearings have their thrust ribs at the large ends of their cup raceways.

50 When the rollers 16 are properly seated between the raceways 4 and 8 of the cup 2 and cone 6, respectively, the end faces 20 of the rollers 16 bear against the rib face 14 on the large or thrust rib 10 of the cone 6. Indeed, a radial load transmitted through the bearing A will urge the rollers 16 toward the large rib 10, as will an axial load. When the rollers 16 are so seated, generally speaking, line contact exists between the side faces 18 of the rollers 16 and the raceways 4 and 8. Moreover, in this context, the conical envelopes formed by the two raceways 4 and 8 have their apexes at a common point along the axis X of rotation, or in other words, the rollers 16 are on apex.

But the raceways 4 and 8 are not truly conical, and the same holds true for the roller side faces 18. Instead, they are slightly curved in profile, usually crowned. This produces a more uniform stress distribution along

the raceways 4 and 8 and roller side faces 18. Further modification to the profiles for the raceways 4 and 8 and side faces 18 may exist to accommodate misalignment produced by extremely heavy loads, and to otherwise distribute loads more uniformly along the raceways 4 and 8. U.S. Patent 4,877,340 describes a process for deriving the profiles for raceways and roller side faces, with the objective of obtaining uniform life along the lines of contact between the roller side faces and the raceways.

Irrespective of how one determines the profiles for the raceways 4 and 8 and the side face 18 of the rollers 16, either the raceways 4 and 8 or the side faces 18, or more likely both, will not lie within true conical envelopes, but instead will be slightly crowned. These crowned profiles are derived from traditional machining operations, such as by grinding or hard turning, and these machining operations leave the raceways 4 and 8, the cone rib face 14, and the roller side and end faces 18 and 20 with machining marks or surface irregularities that extend circumferentially and thus are directional. At the conclusion of the last grind on a bearing so finished, the directional surfaces have a roughness of about 10 to 30 $\mu\text{in Ra}$. A bearing with enhanced finishes, however, receives further finishing to refine its working surfaces, particularly the raceway 4 of the cup 2, the raceway 8 and rib face 14 of the cone 6, and the side faces 18 and end faces 20 of the rollers 16. Using traditional bearing manufacturing practices, these further finishing operations include another grind and conclude with honing or superfinishing. Neither of these procedures affects the profile imparted by the previous grind - and indeed they are controlled so that they do not degrade the profile. The result is an enhanced finish having surface irregularities on the order of 1 to 5 $\mu\text{in Ra}$ (Figs. 3 & 4).

Actually, arithmetic mean roughness (Ra) is only one of several characteristics used to define a working surface, such as either of the raceways 4 and 8 of the bearing A. The following formula defines Ra :

$$\text{Ra} = \frac{1}{L} \int_0^L [z(x)] dx$$

25

where

L is the assessment length

30 Z is the height of the surface profile above and below the centerline

x is the location of each measurement

Then there is the maximum height (R_p) of the profile above its mean line which is also significant.

Perhaps the most significant of all the characteristics is the root-mean-square average slope (Delq) for the irregularities in the profile, this of course being an angular quantity (Fig. 2). It is calculated using the following formula:

$$\text{Delq} = \left[\frac{1}{L} \int_0^L [\theta(x) - \bar{\theta}]^2 dx \right]^{\frac{1}{2}}$$

40

where

θ is the slope of the profile at any given point

45

$$\bar{\theta} = 1/L \int_0^L \theta(x) dx$$

50

Also significant is the surface plasticity index (ψ) which is used to describe the elastic-plastic deformation properties of a surface. The contact surfaces of a bearing that has rolling elements change during the run-in period for the bearing and ultimately arrive at a stable condition. The amount of surface change, which is reflected in the operating torque and temperature, and the duration of the run-in period are presented in the plasticity index - the higher the index the greater the change in torque and temperature during the run-in period and likewise the longer the run-in period. The following formula defines the plasticity index:

$$\psi = \frac{E'}{H} \tan \text{Delq}$$

where

E' is the composite Young's modulus

5

$$E' = \left[\frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2} \right]^{-1}$$

H is the hardness of material.

ν_1 and ν_2 are the Poisson's ratios.

10

E_1 and E_2 are the moduli of elasticity.

A typical working surface on a bearing which is released after a final grind has the following characteristics:

15

Ra	12 μin
Rp	55 μin
Delq	9.0°
ψ	2.24

20

The grind leaves the surface with directional irregularities or machine marks which extend circumferentially.

A typical working surface having an enhanced finish displays the following characteristics (Fig. 2):

25

Ra	4.23 μin .
Rp	22. μin .
Delq	6.2°
ψ	1.54

30

Its irregularities are likewise circumferential.

On the other hand, a typical working surface finished in accordance with the process of the present invention has the following characteristics (Fig. 2):

35

Ra	2.44 μin .
Rp	9.5 μin .
Delq	1.8°
ψ	0.44

40

The plasticity index may be as high as 0.74. Moreover, the surface is isotropic (Figs. 3 & 4).

The process of the present invention relies on conventional machining to bring the working surface of the bearing A to the proper profile with an arithmetic mean roughness (Ra) of typically 10 to 20 μin and usually no more than about 30 μin . Thus, the cup raceway 4, the cone raceway 8 and rib face 14, and the roller side faces 18 and end faces 20 initially have ground finishes with the machining marks or irregularities extending in the circumferential direction. Then the cup 2, cone 6 and rollers 16 are subjected to a chemically assisted vibratory finishing process which to a large measure obliterates the machining marks and renders what remains of them simply nothing more than very shallow pits of no particular orientation. As such, the process, which is sometimes called mechano-chemical vibratory finishing, renders the working surfaces isotropic (Figs. 3 & 4).

45

Basically, the finishing process takes place in a tub which contains a liquid chemical that flows continuously through the tub at a suitable rate, perhaps 1 to 5 gal/hr. A mechanism coupled to the tub vibrates it, and of course the vibrations are transmitted to the liquid chemical within the tub. The chemical, the pH of which is on the order of 1.5, has the capacity to react with the steel such that it attacks the surface of steel. The reaction produces a film or coating which thereafter protects the steel from further attack by the chemical. The film, however, is not firmly bonded to the steel, and indeed is easily displaced, although not by the vibrating chemical. The cup 2, cone 6 and rollers 16 are placed into the liquid chemical within the tub along with appropriate abrading elements, such as small triangular or angle cut cylindrical blocks. Preferably, the abrading elements are formed from a hard substance, such as a ceramic, which is not attacked by the chemical. The abrading elements, owing to the vibration in the chemical, come against the exterior surfaces on the cup 2, cone 6, and

rollers 16 and wear away the protective coating, thus exposing the steel to further attack by the chemical. But the abrading elements only remove the protective coating at higher elevations along the surfaces, so that the surfaces remain protected at their lower elevations. As a consequence, the elevated regions of the surfaces are scoured away, while the depressed regions remain intact. The surface areas of the elevated regions increase to the point that the depressed regions are almost obliterated. The agitation within the chemical continues until the directional machine marks fade into very shallow pockets of essentially no orientation. In other words, the cup 2, cone 6 and rollers 16 remain in the chemical until the working surfaces represented by the raceways 4 and 8, the rib faces 14 and the roller faces 18 and 20 become isotropic surfaces. Up to this point the scouring occurs uniformly on the surfaces, so the profiles left by the original machining remain substantially unchanged.

To be sure, the cup 2, cone 6 and rollers 16 should not remain in the vibrating chemical too long, lest the profiles of the raceways 4 and 8 and roller side faces 18 will be degraded. Generally speaking, the processing in the chemical should cease as soon as the machine marks become isotropic.

Once the working surfaces on the cup 2, cone 6, and rollers 16 become isotropic, the delivery of chemical to the tub is terminated and replaced by a burnishing liquid which flows at a much greater rate, perhaps 20 to 40 gal/hr. The burnishing liquid, which as a pH on the order of 8.5, neutralizes what remains of the liquid chemical and otherwise removes the protective coating remaining on the cup 2, cone 6 and rollers 16, bringing their surfaces, including the raceways 4 and 8, the rib face 14 and the roller faces 18 and 20, which represent the working surfaces, down to the metal. Each working surface exhibits a mirror-like appearance.

REM Chemicals, Incorporated, of Southington, Connecticut, sells the liquid chemical and the burnishing liquid for performing the process which REM Chemicals designates as the FERROMIL process. It has acquired several U.S. patents on the process and on compositions and devices used in the process. U.S. Patent 4,491,500 describes the basic process; U.S. Patent 4,705,594 likewise describes process, but focuses on liquid chemicals. U.S. Patent 4,818,333 is devoted primarily to the so-called media or abrading elements used in the process. On the other hand, U.S. Patent 5,158,629 relates primarily to the burnishing liquid.

A bearing provided with isotropic working surfaces in accordance with the present invention has a very low surface plasticity index - indeed, one so low that the bearing requires no-run-in to bring it to its optimum operating condition. When compared to an equivalent bearing having enhanced finishes on its working surface, the bearing with the isotropic surfaces displays superior operating characteristics.

In this regard, two single row tapered roller bearings, which were identical in every respect, except for the finish of their operating surfaces, and which had further never seen use, were set in operation under identical conditions, including with the same radial load and with the same lubrication. The one bearing had working surfaces finished in accordance with the present invention, that is, its raceways 4 and 8, its rib face 14, and its roller side and end faces 18 and 20 were all isotropic and otherwise corresponded to the characteristics of a typical isotropic working surface previously described. The other bearing had the very same working surfaces provided with an enhanced finish meeting the characteristics previously described for such a surface. After operating each bearing for about one hour with no load, the radial load was gradually applied to each bearing until at the end of about 7 hours, each bearing was fully loaded at 27500 lbs. By this time the bearing with the isotropic finish had reached its normal operating temperature and it continued to operate at that temperature (Fig. 5). The bearing with the enhanced finish reached a substantially higher temperature at the same time, but over the next 12 hours that temperature dropped, which is typical of a bearing undergoing run-in (Fig. 5). At about 20 hours the bearing cooled to its normal operating temperature which was higher than the operating temperature for the bearing with the isotropic surfaces. The torques required to sustain the operation of the bearings exhibited similar characteristics. For the bearing with the isotropic working surfaces, it rose as the load was applied and then remained constant (Fig. 6). For the bearing with enhanced finish on its working surfaces, the torque rose substantially on initial loading to a maximum at the onset of the full load, and then decreased, becoming constant at about 20 hours (Fig. 6). But the torque at which the bearing with the enhanced finish leveled off was higher than the torque at which the bearing with the isotropic finish leveled off. Moreover, the bearing having the isotropic surfaces exhibited greater fatigue life than the bearing with enhanced surfaces. It likewise exhibits greater fatigue life than bearings finished with final grinds, and of course lower temperature and torque as well.

While the process is described in connection with a tapered roller bearing, it is also useful in finishing the working surfaces on other types of bearings such as cylindrical roller bearings, spherical roller bearings and ball bearings.

Cylindrical roller bearings have raceways and rib faces which serve as working surfaces and of course rollers which move along those working surfaces and in their own right have working surfaces. Preferably, all of the working surfaces have an isotropic finish. In a ball bearing, the working surfaces include the raceways and the spherical surfaces of the rolling elements and preferably all have isotropic finishes.

This invention is intended to cover all changes and modifications of the example of the invention herein chosen for purposes of the disclosure which do not constitute departures from the spirit and scope of the invention.

5

Claims

1. A process for finishing a metal race having a working surface along which another bearing component will move in contact with the working surface, the working surface having irregularities of a directional character, said process comprising: immersing the race in a liquid chemical which reacts with the metal of the race along the working surface such that it forms a protective coating on the working surface, with the coating essentially preventing the chemical from further reacting with the metal unless the coating is disturbed; and continuously removing the coating along higher regions of the working surface so that the chemical reacts with those higher regions, whereby the higher regions are eliminated, the removal of the higher regions continuing until the irregularities are essentially nondirectional, whereby the working surface is rendered substantially isotropic.
2. A process according to claim 1 wherein the initial direction of the irregularities is circumferential.
3. A process according to claim 1 wherein the step of continuously removing the coating includes subjecting the coating to solid abrading elements which contact the coating and wear it away at the higher regions of the working surface.
4. A process according to claim 3 wherein the step of continuously removing the coating includes agitating the liquid chemical in which the race and abrading elements are located, so that the abrading elements repeatedly come against the coating on the working surface.
5. A process according to claim 4 and further comprising thereafter separating the race from the chemical and in the absence of the chemical removing the coating remaining on the working surface.
6. A process according to claim 5 wherein the working surface is a raceway on the race.
7. A process according to claim 1 wherein the step of immersing the race and continuously removing the coating does not substantially alter the profile of the working surface.
8. A process for finishing the working surfaces of a tapered roller bearing having a cup provided with a raceway that represents one of the working surfaces, a cone provided with a raceway and, at the large end of the raceway, a rib face, both of which represent more working surfaces, and tapered rollers having side faces and large end faces which represent still more working surfaces, when the bearing is assembled, the cone being within the cup and the rollers being between the cup and the cone with their side faces contacting the raceways and their large end faces contacting the rib face, the cup, cone, and rollers all being formed from steel, said process comprising: machining the cup, the cone and the rollers to provide their working surfaces with proper profiles, the working surfaces being left with circumferentially directed irregularities as a result of the machining; immersing each of the cup, cone and rollers in a liquid chemical having the capacity to react with the steel from which the cup, cone and rollers are formed and to form a protective coating over the steel during the reaction, with the coating serving to inhibit further reaction until disturbed, whereby the liquid chemical reacts with the steel of the cup, cone and rollers along the working surfaces and further produces a protective coating on the working surfaces; placing solid abrading elements in the liquid chemical; agitating the liquid chemical such that the abrading elements contact the protective coating along the working surfaces and remove it from higher elevations of the working surfaces to further expose the higher elevations to the chemical, so that the higher elevations are further scoured away, the agitation and scouring continuing until the irregularities in the working surfaces become nondirectional and render the working surfaces isotropic, but without substantially altering the profiles of the working surfaces; and thereafter in the absence of the chemical removing the protective coating from the cup, cone and rollers and the working surfaces on them.
9. The process according to claim 8 wherein the process of removing the protective coating in the absence of the chemical includes immersing the cup, cone and rollers in a burnishing liquid and agitating the burnishing liquid.

10. The process according to claim 8 wherein the agitation and scouring continue until the irregularities in the working surfaces have arithmetic mean roughness (Ra) of not more than about 3.0 μ in.
- 5 11. The process according to claim 10 wherein the agitation and scouring continue until the irregularities in the working surface have a root mean square slope (Delq) of not more than about 3°.
12. The process according to claim 8 wherein the agitation and scouring continue until the plasticity index of the working surfaces is no more than about 0.74.
- 10 13. A tapered roller bearing comprising: a metal first race provided with a raceway; a metal second race provided with a raceway that is presented toward the raceway of the first race; a rib having a rib face at the end of the raceway on one of the races; rollers of metal arranged in a circular row between the raceways of the first and second races and having side faces which contact the raceways and end faces which bear against the rib face; the raceways, rib face, and roller side and end faces containing irregularities that are nondirectional so that the surfaces represented by the raceways, rib face, and roller side and end faces are isotropic.
- 15 14. A bearing according to claim 13 wherein the profiles for the raceways and the roller side faces and end faces are derived by mechanical machining.
- 20 15. A bearing according to claim 14 wherein the machining leaves the raceways and roller end and side faces with irregularities that impart an arithmetic mean roughness (Ra) of not more than about 30 μ in., and wherein the ground raceways and roller side and end faces are reduced to an arithmetic mean roughness (Ra) of no more than about 3 μ in. and rendered isotropic all by immersing the races and rollers in a liquid chemical that reacts with the metal of the races and rollers along the raceways and roller side and end faces and produces a protective coating which covers the raceways and roller side and end and substantially inhibits further reaction until removed, and continuously removing the coating at higher elevations along the raceways and roller side and end faces so that the raceways and roller side and end faces are scoured away at those higher elevations until they are isotropic.
- 25 16. A bearing according to claim 13 which further does not exhibit an increased temperature or torque coupled with a subsequent decrease in those characteristics during the initial operation of the bearing.
- 30 17. A rolling element bearing comprising:
 - an outer race having at least one working surface;
 - an inner race having at least one working surface;
 - 35 rolling elements interposed between said inner and outer races and contacting the races at the working surfaces on the races;
 - said rolling elements and at least one of said working surfaces having an isotropic surface finish.
- 40 18. The bearing of claim 17 wherein said working surface of said inner race comprises a first raceway.
19. The bearing of claim 18 wherein said isotropic finish is provided on said first raceway.
20. The bearing of claim 17 wherein said working surface of said outer race comprises a second raceway.
- 45 21. The bearing of claim 17 wherein said isotropic finish is provided on said second raceway.
22. The bearing of claim 17 wherein one of the races is provided with a rib having a working surface, the working surface on the rib is provided with an isotropic finish.
- 50 23. The bearing of claim 22 wherein said working surface further comprises said first raceway of said inner race.
24. The bearing of claim 23 wherein said working surface further comprises said second raceway of said outer race.

55

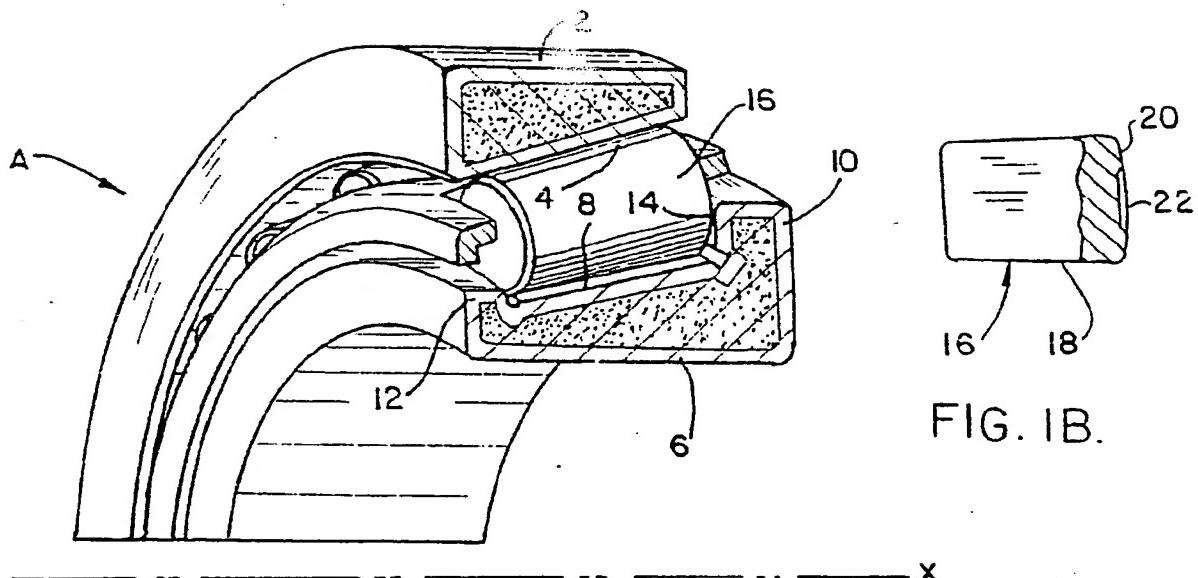


FIG. 1B.

FIG. 1A.

(1) Enhanced Finishing Roller Body:



FIG. 2A.

$$\begin{aligned} Ra &= 4.23 \mu\text{in.} \\ Rp &= 22 \mu\text{in} \\ Delq &= 6.2 \deg. \\ \Psi &= 1.54 \end{aligned}$$

(2) Isotropic Finishing Roller Body:

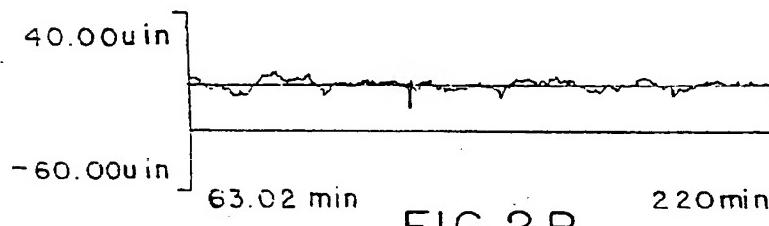
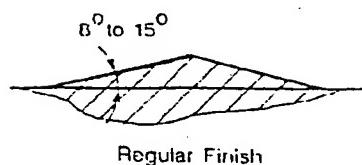


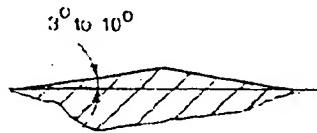
FIG. 2B.

$$\begin{aligned} Ra &= 2.44 \mu\text{in.} \\ Rp &= 9.5 \mu\text{in} \\ Delq &= 1.8 \deg. \\ \Psi &= 0.44 \end{aligned}$$

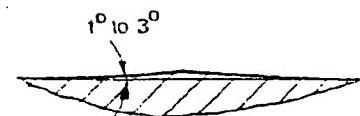
* Example of the RMS Slope of the Profile (Delq):



Regular Finish



Enhanced Finish



Isotropic Finish

FIG. 2C.

FIG. 2D.

FIG. 2E.

Roller Body with Enhanced Finishing:

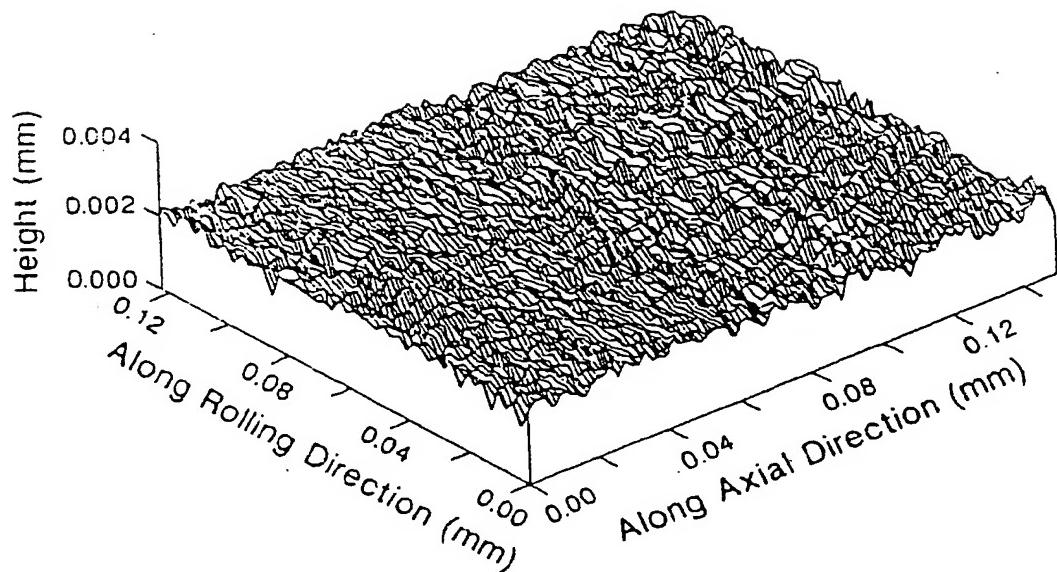


FIG. 3A.

Roller Body with Isotropic Finishing:

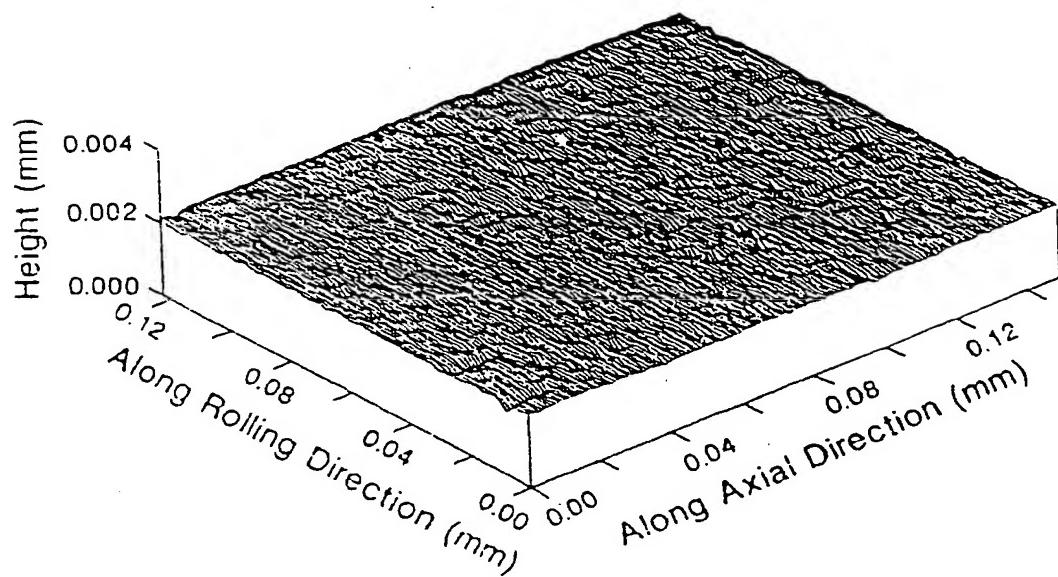


FIG. 3B.

SEM Photograph of Roller Body with Enhanced Finishing

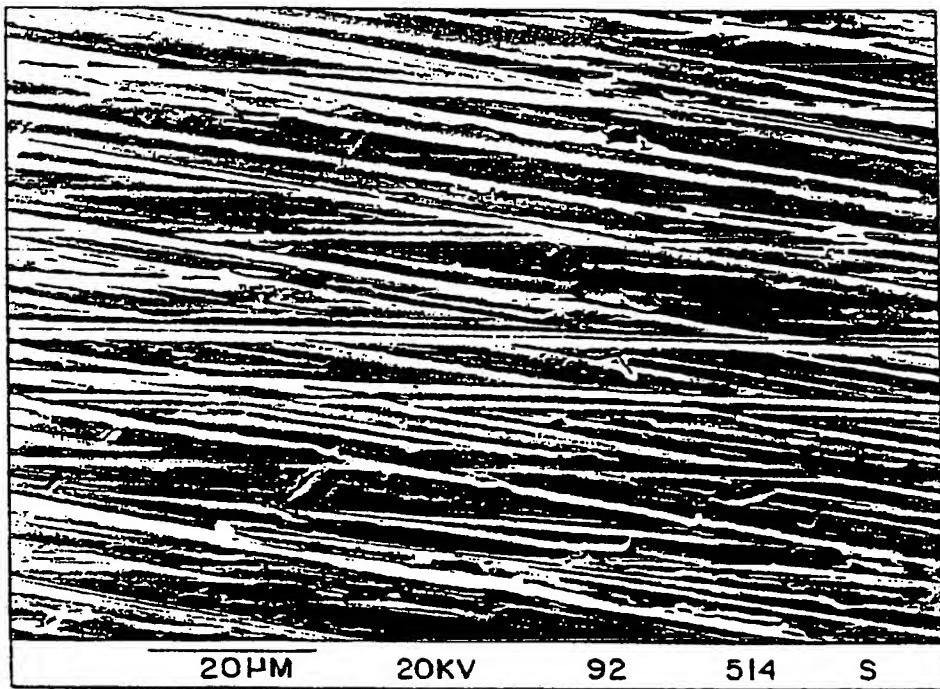


FIG. 4A.

SEM Photograph of Roller Body with Isotropic Finishing

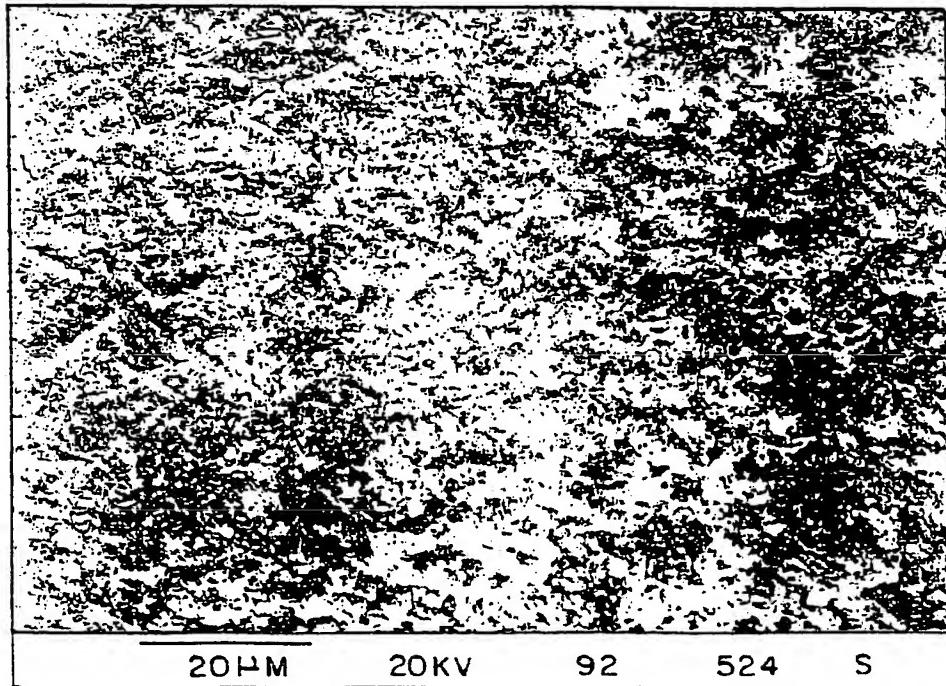


FIG. 4B.

67700 BEARING CUP TEMP. OF LIFE TEST.
 SAE 20 OIL, INLET TEMP. = 100°F
 27,500 LBS RADIAL LOAD AT RUN-IN PERIOD.

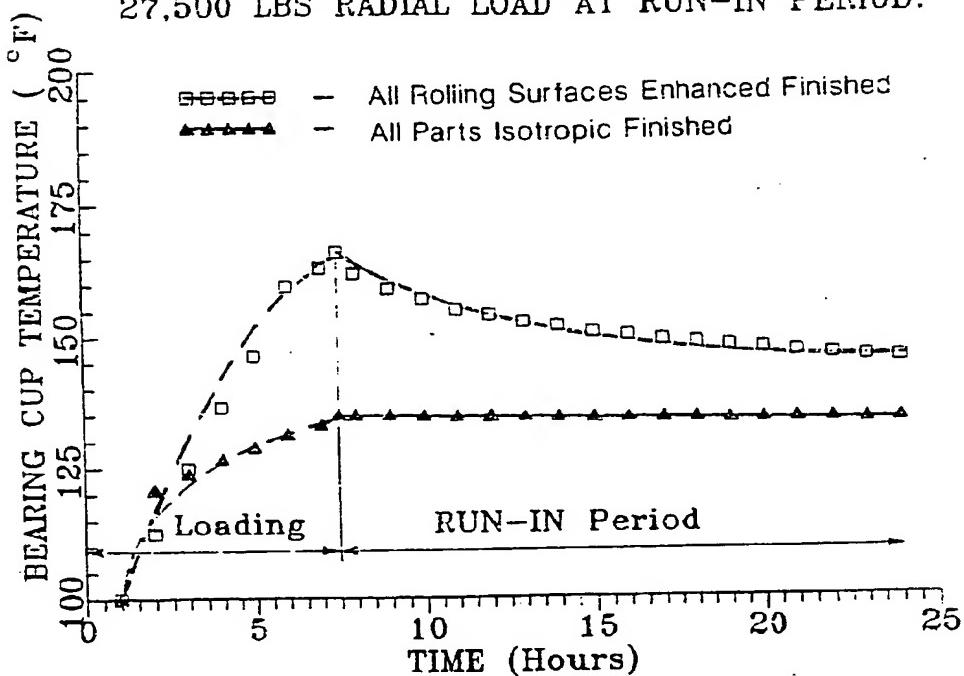


FIG. 5.

67700 BEARING TORQUE DATA OF LIFE TEST
 SAE 20 OIL, INLET TEMP. = 100°F
 27,500 LBS RADIAL LOAD FOR RUN-IN PERIOD.

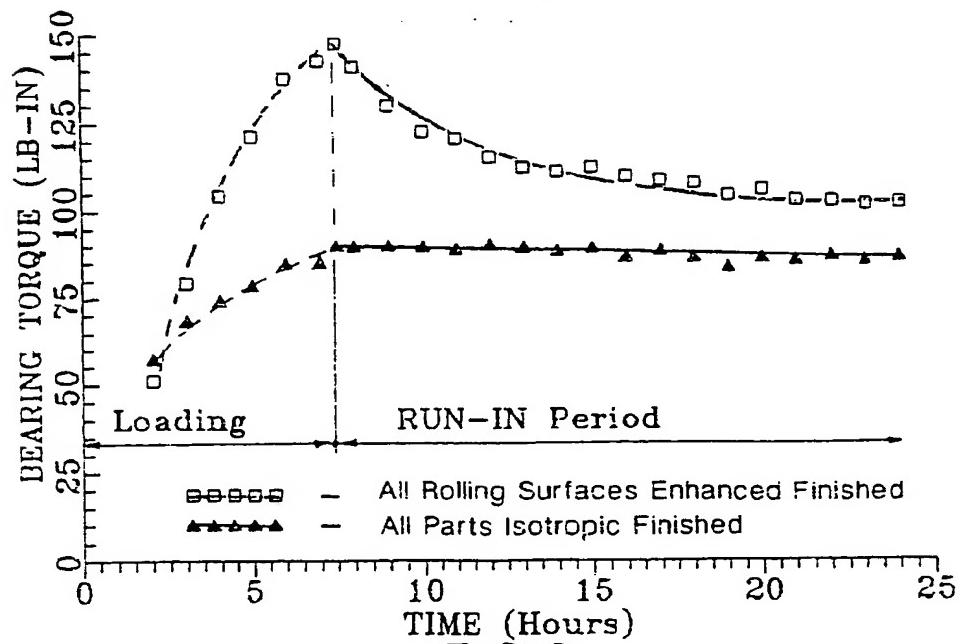


FIG. 6.



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 94 63 0066

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int.Cl.6)						
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim							
A,D	US-A-4 491 500 (M. MICHAUD ET AL.) * the whole document * ---	1,3, 7-10,15	F16C33/64 F16C33/14 C23C22/73 C23F3/00						
A,D	US-A-4 705 594 (R. ZOBBI ET AL) * the whole document * ---	1,8,13							
A,D	US-A-4 818 333 (M. MICHAUD) * the whole document * ---	1,8,13, 17							
A,D	US-A-5 158 629 (R. ZOBI) * the whole document * ---	1,8,13, 17							
A	US-A-4 789 438 (N. POLAN) * column 5 * ---	1							
A	FR-A-2 640 009 (NIPPON SEIKO) ---								
A	PATENT ABSTRACTS OF JAPAN vol. 10, no. 49 (C-330) 26 February 1986 & JP-A-60 194 084 (COPAL) 2 October 1985 * abstract * -----		TECHNICAL FIELDS SEARCHED (Int.Cl.6) F16C C23C C23F						
<p>The present search report has been drawn up for all claims</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 33%;">Place of search</td> <td style="width: 33%;">Date of completion of the search</td> <td style="width: 34%;">Examiner</td> </tr> <tr> <td>THE HAGUE</td> <td>3 March 1995</td> <td>BEGUIN, C</td> </tr> </table> <p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p>				Place of search	Date of completion of the search	Examiner	THE HAGUE	3 March 1995	BEGUIN, C
Place of search	Date of completion of the search	Examiner							
THE HAGUE	3 March 1995	BEGUIN, C							

EPO FORM 1500 03/82 PD/01/91